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(54) Title: PROJECTION OBJECTIVE HAVING A HIGH APERTURE AND A PLANAR END SURFACE

(57) Abstract: A projection objective for imaging a pattern provided in an object plane of the projection objective onto an image plane of the projection objective suitable for microlithography projection exposure machines has a plurality of optical elements transparent for radiation at an operating wavelength of the projection objective. At least one optical element is a high-index optical element made from a high-index material with a refractive index $n \geq 1.6$ at the operating wavelength.

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Description

Projection objective having a high aperture and a planar end surface

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to a projection objective for imaging a pattern provided in an object plane of the projection objective onto an image plane of the projection objective. The projection objective may be used for microlithography projection exposure machines. The invention relates, in particular, to exposure machines for semiconductor structures which are designed for immersion operation, that is to say in an aperture range where the image side numerical aperture NA is greater than 1.0.

Description of the Related Art

In the case of reducing optical imaging, in particular of projection lithography, the image side numerical aperture NA is limited by the refractive index of the surrounding medium in image space. In immersion lithography the theoretically possible numerical aperture NA is limited by the refractive index of the immersion medium. The immersion medium can be a liquid or a solid. Solid immersion is also spoken of in the latter case.

However, for practical reasons the aperture should not come arbitrarily close to the refractive index of the last medium (i.e. the medium closest to the image), since the propagation angles then become very large relative to the optical axis. It has proven to be practical for the aperture not substantially to exceed approximately 95% of the refractive index of the last medium of the image side. This corresponds to propagation angles of approximately 72° relative to the optical axis. For 193 nm, this

corresponds to a numerical aperture of NA = 1.35 in the case of water (n_{H2O} = 1.43) as immersion medium.

With liquids whose refractive index is higher than that of the material of the last lens, or in the case of solid immersion, the material of the last lens element (i.e. the last optical element of the projection objective adjacent to the image) acts as a limitation if the design of the last end surface (exit surface of the projection objective) is to be planar or only weakly curved. The planar design is advantageous, for example, for measuring the distance between wafer and objective, for hydrodynamic behaviour of the immersion medium between the wafer to be exposed and the last objective surface, and for their cleaning. The last end surface must be of planar design for solid immersion, in particular, in order to expose the wafer, which is likewise planar.

For DUV (operating wavelength of 248 nm or 193 nm), the materials normally used for the last lens are fused silica (synthetic quartz glass, SiO_2) with a refractive index of n_{SiO2} = 1.56 or CaF_2 with a refractive index of n_{CaF2} = 1.50. The synthetic quartz glass material will also be referred to simply as "quartz" in the following. Because of the high radiation load in the last lens elements, at 193 nm calcium fluoride is preferred for the last lens, in particular, since synthetic quartz glass would be damaged in the long term by the radiation load. This results in a numerical aperture of approximately 1.425 (95% of n = 1.5) which can be achieved. If the disadvantage of the radiation damage is accepted, quartz glass still allows numerical apertures of 1.48 (corresponding to approximately 95% of the refractive index of quartz at 193 nm). The relationships are similar at 248 nm.

SUMMARY OF THE INVENTION

One object of the invention is to provide a high-aperture projection objective which circumvents the disadvantages of conventional designs

with immersion media such as water or with lens materials such as fused silica and CaF_2. It is another object of the invention to provide projection objectives suitable for immersion lithography at image side numerical apertures of at least NA = 1.35 having moderate size and material consumption.

As a solution to this and other objects, this invention, according to one formulation, provides a projection objective for imaging a pattern provided in an object plane of the projection objective onto an image plane of the projection objective suitable for microlithography projection exposure machines comprising: a plurality of optical elements transparent for radiation at an operating wavelength of the projection objective; wherein at least one optical element is a high-index optical element made from a high-index material with a refractive index $n \geq 1.6$ at the operating wavelength.

One embodiment consists in a radiation-proof lithography objective with image side numerical apertures which are preferably greater than or equal to NA = 1.35 and for which at least the last lens element consists of a high-index material (refractive index $n > 1.6$, in particular $n > 1.8$). In the case of the reduction ratio, customary in lithography, of (absolute) 4:1 ($|\beta| = 0.25$), the object-side (mask-side) numerical aperture is then $NA_{obj} \geq 0.33$, preferably $NA_{obj} \geq 0.36$.

Various aspects of the invention are explained below in more detail using exemplary embodiments for 193 nm. In the examples, a material used for the last lens element or a part thereof is sapphire (Al_2O_3), while the remaining lenses are made from fused silica. However, the examples can be transferred to other high-index lens materials and other wavelengths. For example, for 248 nm it is possible to use Germanium dioxide (GeO_2) as material for the last lens or a part thereof. By contrast with sapphire, this material has the advantage that it is not birefringent. However, the material is no longer transparent at 193 nm.

In the case of liquid immersion, an NA > 1.35 may be reached if an immersion liquid with a higher refractive index than water is used. Cyclohexane (refractive index n=1.556) was used in some application examples.

Immersion media with n>1.6 are currently regarded as realistic.

If an immersion liquid is used, the thickness of the high-index liquid, that is to say the immersion liquid, can preferably be between 0.1 and 10 mm. Smaller thicknesses within this range may be advantageous since the high-index immersion media generally also exhibit a higher absorption.

The previous and other properties can be seen not only in the claims but also in the description and the drawings, wherein individual characteristics may be used either alone or in sub-combinations as an embodiment of the invention and in other areas and may individually represent advantageous and patentable embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a longitudinally sectioned view of a first embodiment of a catadioptric projection objective according to the invention;

Fig. 2 is a longitudinally sectioned view of a second embodiment of a catadioptric projection objective according to the invention;

Fig. 3 is a longitudinally sectioned view of a third embodiment of a catadioptric projection objective according to the invention;

Fig. 4 is a longitudinally sectioned view of a fourth embodiment of a catadioptric projection objective according to the invention;

Fig. 5 is a longitudinally sectioned view of a fifth embodiment of a catadioptric projection objective according to the invention;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description of preferred embodiments of the invention, the term "optical axis" shall refer to a straight line or sequence of straight-line segments passing through the centers of curvature of the optical elements involved. The optical axis can be folded by folding mirrors (deflecting mirrors). In the case of those examples presented here, the object involved is either a mask (reticle) bearing the pattern of an integrated circuit or some other pattern, for example, a grating pattern. In the examples presented here, the image of the object is projected onto a wafer serving as a substrate that is coated with a layer of photoresist, although other types of substrate, such as components of liquid-crystal displays or substrates for optical gratings, are also feasible.

Where tables are provided to disclose the specification of a design shown in a figure, the table or tables are designated by the same numbers as the respective figures.

Fig. 1 shows a first embodiment of a catadioptric projection objective 100 according to the invention designed for ca. 193 nm UV working wavelength. It is designed to project an image of a pattern on a reticle (or mask) arranged in the object plane OP into the image plane IP on a reduced scale, for example, 4:1, while creating exactly two real intermediate images IMI1 and IMI2. A first refractive objective part ROP1 is designed for imaging the pattern in the object plane into the first intermediate image IMI1, a second, catoptric (purely reflective) objective part COP2 images the first intermediate image IMI1 into the second intermediate image IMI2 at a magnification close to 1:1, and a third, refractive objective part ROP3 images the second intermediate image

IMI2 onto the image plane IP with a strong reduction ratio. The second objective part COP2 comprises a first concave mirror CM1 having the concave mirror surface facing the object side, and a second concave mirror CM2 having the concave mirror surface facing the image side. The mirror surfaces are both continuous or unbroken, i.e. they do not have a hole or bore. The mirror surfaces facing each other define an intermirror space, enclosed by the curved surfaces defined by the concave mirrors. The intermediate images IMI1, IMI2 are both situated geometrically inside the intermirror space, at least the paraxial intermediate images being almost in the middle thereof well apart from the mirror surfaces.

Each mirror surface of a concave mirror defines a "curvature surface" or "surface of curvature" which is a mathematical surface extending beyond the edges of the physical mirror surface and containing the mirror surface. The first and second concave mirrors are parts of rotationally symmetric curvature surfaces having a common axis of rotational symmetry.

The system 100 is rotational symmetric and has one straight optical axis AX common to all refractive and reflective optical components. There are no folding mirrors. The concave mirrors have small diameters allowing to bring them close together and rather close to the intermediate images lying in between. The concave mirrors are both constructed and illuminated as off-axis sections of axial symmetric surfaces. The light beam passes by the edges of the concave mirrors facing the optical axis without vignetting.

Catadioptric projection objectives having this general construction are disclosed e.g. in the US provisional applications with serial numbers 60/536,248 filed on January 14, 2004, 60/587,504 filed on July 14, 2004 and a subsequent extended application filed on October 13, 2004. The contents of these applications is incorporated into this application by

reference. It is one characterizing feature of this type of catadioptric projection objectives that pupil surfaces (at axial positions where the chief ray intersects the optical axis) are formed between the object plane and the first intermediate image, between the first and the second intermediate image and between the second intermediate image and the image plane and that all concave mirrors are arranged optically remote from a pupil surface, particularly at positions where the chief ray height of the imaging process exceeds a marginal ray height of the imaging process. Further, it is preferred that at least the first intermediate image is located geometrically within the intermirror space between the first concave mirror and the second concave mirror. Preferably, both the first intermediate image and the second intermediate image are located geometrically within the intermirror space between the concave mirrors.

The exemplary examples described below share these basic characteristics which allow immersion lithography at numerical apertures NA > 1 with optical systems that can be built with relatively small amounts of optical material.

Fig. 1 shows as first exemplary embodiment a lithography objective for 193 nm with a sapphire lens and cyclohexane as immersion medium in conjunction with an image-side numerical aperture of NA = 1.45. The sapphire lens is the last optical element LOE closest to the image plane. The image-side working distance is 1 mm. The catadioptric design has two concave mirrors, chiefly for chromatic correction and Petzval correction, and an intermediate image respectively upstream and downstream of the pair of mirrors. The intermediate images are, however, not fully corrected and serve primarily for the geometrical limitation of the design and for separating two beam paths running toward a mirror and runing from a mirror after reflection therupon. The image field (on the wafer) is rectangular. The external field radius (on the wafer side) is 15.5 mm, the inner one 4.65 mm. The result of this is a rectangular field of 26 x 3.8 mm.

The aperture diaphragm (aperture stop AS, system aperture) is arranged in the first refractive objective part ROP1 in the first exemplary embodiment. This is advantageous in order, on the one hand, to fashion a smaller variable aperture diaphragm, and on the other hand largely to protect the subsequent objective parts (seen from the object plane (mask plane)) against useless and interfering radiation loads when stopping down the aperture diaphragm. The rear diaphragm plane in the image-side objective part ROP3, i.e. a position where an aperture stop could be placed, is positioned in a region between the lens of maximum diameter LMD and the image plane IP in the convergent beam path.

Formed in the object-side front refractive partial objective ROP1 is a waist (constriction of the beam and lens diameters) which serves primarily for correcting the image field curvature (Petzval sum). The aperture stop AS is arranged at the waist.

The use of CaF_2 for the last lens is not to be preferred, since this requires a numerical aperture that is as far as possible not greater than 1.425 (~95% of the refractive index of CaF_2). At 193 nm, sapphire (Al_2O_3) is used in this example as high-index material in the last lens element LOE. In all embodiments shown in the figures optical elements made of sapphire are shaded gray for easier reference.

The birefringence occurring when sapphire is used is largely compensated by splitting the last lens (last optical element LOE) into two lens elements LOE1 and LOE2 and rotating the two lens elements relative to one another around the optical axis. In this case, the separation interface SI (contact surface of the two lens elements LOE1 and LOE1) is preferably curved such that both lens elements have similar refractive power. Alternatively, it is possible to use for the compensation a second element made from sapphire which is located at a site in the objective which acts similarly in optical terms, for example in

the vicinity of the intermediate images or in the vicinity of the object plane. In the present case, the last sapphire lens LOE is split into two lens elements LOE1 and LOE2 which act virtually identically. The front radius of the sapphire lens LOE (i.e. the radius of the light entry side) is designed such that an aperture beam, i.e. a beam running towards the image at the parimeter of the convergent light bundle, toward the center of the image field passes through the interface virtually without being refracted, that is to say strikes the interface virtually perpendicularly (lens radius is virtually concentric with the point of intersection of the image plane with the optical axis). The radius of the splitting interface SI between the two lens elements of the split sapphire lens is flatter (radius > 1.3 times the distance from the image plane where a wafer can be placed).

Compensation of birefringence effects by relative rotation of elements made of birefringent material is described in detail e.g. in patent applications DE 101 23 725 A1 (corresponding e.g. to US 2004/0190151 A1) or WO 03/077007 A2 by the applicant. Catadioptric projection objectives having a final lens element closest to the image plane designed as a split final lens made from a birefringent material (calcium fluoride) are known from US 6,717,722 B.

The specifications for the design of Fig. 1 are summarized in Table 1. The leftmost column lists the number of the refractive, reflective, or otherwise designated surface, the second column lists the radius, r, of that surface [mm], the third column lists the distance, d [mm], between that surface and the next surface, a parameter that is referred to as the "thickness" of the optical element, the fourth column lists the material employed for fabricating that optical element, and the fifth column lists the refractive index of the material employed for its fabrication. The sixth column lists the optically utilizable, clear, semi diameter [mm] of the optical component. In the tables, a radius value r=0 is given for planar surfaces having infinite radius.

In the case of this particular embodiment, fifteen surfaces are aspherical surfaces. Table 1A lists the associated data for those aspherical surfaces, from which the sagitta of their surface figures as a function of the height h may be computed employing the following equation:

$$p(h) = [((1/r)h^2)/(1 + SQRT(1 - (1 + K)(1/r)^2h^2)] + C1 \cdot h^4 + C2 \cdot h^6 + \ldots ,$$

where the reciprocal value (1/r) of the radius is the curvature of the surface in question at the surface vertex and h is the distance of a point thereon from the optical axis. The sagitta p(h) thus represents the distance of that point from the vertex of the surface in question, measured along the z-direction, i.e., along the optical axis. The constants K, C1, C2, etc., are listed in Table 1A.

Likewise, the specifications of the following embodiments are represented in similar manner in tables 2, 2A for Fig. 2, tables 3, 3A for Fig. 3, tables 4, 4A for Fig. 4 and tables 5, 5A for Fig. 5.

In accordance with the projection objective 200 according to Fig. 2 the last optical element LOE on the image side has the overall shape of a plano-convex lens. The lens is subdivided into two optical elements LOE1 and LOE2 which are contacted along a plane splitting interface SI. Specifically, a quartz glass lens LOE1 with a positive radius of curvature of the entry surface and a rear planar surface is wrung onto one (or two) plane-parallel plates LOE2 made from sapphire. This yields values of NA no higher than possible in quartz glass, but there is the advantage that the angle of propagation of the light beams is reduced in the last objective part where the aperture is greatest owing to the high-index medium. This is advantageous when considering the reflection losses and scattered light effects at the interface and at possible protective layers on the last end surface, which constitute a problem for these otherwise very large angles of propagation. The largest angles then

occur only at the wrung surface between the quartz lens LOE1 and the first high-index plane-parallel plate LOE2. This wrung surface (contact interface where the adjacent optical elements are adhered to each other by wringing) is protected against contamination and damage, and can be designed with a coating which is sensitive to environmental influences as well. If two plane-parallel plates are used to form the plane-parallel high-index element LOE2, then the two plane-parallel plates made from sapphire can be rotated relative to one another around the optical axis virtually ideally to compensate the birefringence effect for the S- and P-polarisations in the x- and y-directions which are chiefly required for imaging the semiconductor structures.

However, because of its lower refractive index, the quartz lens LOE1 has the effect here that – because of its lesser collecting effect – very large lens diameters are required even for image-side numerical apertures of a projection objective of limited overall length which are not really so large. In the second exemplary embodiment (Fig. 2), the aperture is NA = 1.35, but the lens diameters are greater than in the first exemplary embodiment. Here, the lens diameter is already over 143 mm and thus virtually 212 times the numerical aperture, while in the exemplary embodiment in Fig. 1 only 200 times the numerical aperture is reached. In particular, in the exemplary embodiment in Fig. 2 at 143 mm the maximum half lens diameter is even greater than the mirror semi-diameter at approximately 136 mm.

In order to minimize the diameter of the largest lens elements of the projection objective, and at the same time to minimize the effect of the birefringence, in an alternative embodiment (projection objective 300) of the design example with NA = 1.45 the last lens element LOE comprises a thin sapphire lens LOE1 with positive refractive power, a spherically curved entry surface and a planar exit surface, which is wrung onto a thin quartz glass plate LOE2 (exemplary embodiment 3 in Fig. 3). The plane-parallel quartz glass plate providing the exit surface of the

objective can then be interchanged upon the occurrence of damage owing to the radiation load. A wrung quartz plate therefore also acts as interchangeable protection of the sapphire lens LOE1 against contamination and/or scratches or destruction. Embodiment 3 is adapted to Cyclohexane as an immersion fluid, which has a refractive index (n = 1.556) similar to that of fused silica (n = 1.560) used for the plate in contact with the immersion fluid.

In these cases, the NA is limited by the refractive index of the quartz glass. However, by comparison with a design having a last lens made from pure quartz glass the result upstream of the last lens is smaller beam angles and therefore also smaller diameters of the overall objective and lower sensitivities (interference susceptibilities to manufacturing tolerances) of the last lens element. In embodiment 3, at 135 mm the maximum lens diameter is now approximately 186 times the numerical aperture.

Of course, the present invention can also be used for objectives of low numerical aperture, in order to reduce substantially the diameter of previous projection objectives. This advantageously affects the price of the projection objective, since the amount of material can be reduced substantially.

The exemplary fourth embodiment (Fig. 4) shows a lithography objective 400 for 193 nm with a monolithic last lens made of sapphire and water (n_{H2O} = 1.43) as immersion medium for NA = 1.35 with a working distance of 1 mm. The top side (entrance side) of the monolithic (one part, not split) sapphire lens LOE is aspheric, and the aperture stop AS is situated in the rear part of the image side refractive objective part ROP3 in the region of convergent radiation between the region of largest beam diameter in the third objective part ROP3 at biconvex lens LMD with largest diameter and the image plane IP. The maximum lens diameter is limited to less than 190 times the numerical aperture.

Even higher numerical apertures than NA = 1.45 are possible with the aid of high-index materials for at least the last lens element.

The fifth exemplary embodiment 500 (Fig. 5) is designed for solid immersion (contact projection lithography) with a plano-convex sapphire lens LOE ($n_{sapphire}$ = 1.92) for an NA = 1.6. Consequently, even numerical apertures of up to NA > 1.8 are feasible in principle. In the example, the outer field radius on the wafer side is at 15.53 mm, and the inner one is at 5.5 mm, that is to say the size of the rectangular field here is 26 x 3 mm.

Since the high-aperture beams with apertures of NA > 0.52 experience total reflection upon transition from sapphire to air at the plane exit surface, working distances of less than the wavelength must be realized for solid immersion in order to efficiently use evanescent waves for the exposure of the wafer. This can be performed in vacuo by bringing the wafer to be exposed constantly to, for example, 100 nm ($\approx \lambda/2$) in the vicinity of the last lens surface.

However, since on the basis of the power transmission, which drops exponentially with distance, through evanescent fields small changes in distance result in strong fluctuations in uniformity, it is advantageous to bring the wafer into direct mechanical contact with the last end surface (exit surface) of the projection objective. To be exposed, the wafer can be wrung onto the last planar lens surface (contact surface CS) for this purpose in order to obtain a mechanical contact between the exit surface of the projection objective and the incoupling surface associated to the substrate. A step-and-scan mode or stitching methods of exposure is to be preferred in this case, that is to say larger regions than the image field are exposed in individual steps, the reticle mask being correspondingly adjusted for alignment instead of, as previously customary, the wafer. This is also advantageous because owing to the

reducing imaging the reticle can be adjusted with less accuracy than an adjustment of the wafer. Mutually adjoining exposure regions (target areas) or sequential levels of the semiconductor structure from subsequent exposure steps are thereby brought into overlay by lateral and axial movement and rotation of the reticle mask in order thereby to expose the semiconductor structures onto the possibly also defectively wrung wafers with an overlay accuracy of better than a few nm. Alignment marks, for example, of the reticle are brought into agreement for this purpose with alignment marks already exposed on the wafer.

The release of the wafer from the last surface is preferably performed in vacuo. If required, there is located between the wafer and last planar lens surface a thin layer (pellicle/membrane) which can be exchanged after each exposure step, for example. This membrane can, for example, also remain bonded on the wafer and assist in the separation and serves, in particular, as protection for the last planar lens surface. The latter can optionally be protected in addition by a thin protective layer.

In the case of solid immersion, standing waves of high intensity can be produced during the exposure in the edge region of the last lens surface owing to the instances of imaging interference. It is therefore even advantageous for the repeated exposure of a structure onto a wafer when the wafer is inaccurately positioned by chance in certain ranges of a few micrometers owing to the wringing, something which is compensated by adjustment using the reticle in order to prevent systematic structures from being burnt into the last lens.

All exemplary embodiments discussed above are catadioptric projection objectives with exactly two concave mirrors and exactly two intermediate images, where all optical elements are aligned along one straight, unfolded optical axis. The uniform basic type of projection objective chosen to explain preferred variants of the invention is intended to help illustrate some basic variants and technical effects and advantages

related to different variants of the invention. However, the demonstrated use of lenses or lens elements made of high refractive index material (e.g. $n \geq 1.6$ or even $n \geq 1.8$) in projection objectives particularly for operating wavelength in the deep ultraviolet range (DUV) is not restricted to this type of projection objectives. The invention can also be incorporated into purely refractive projection objectives. In those types, the last optical element closest to the image plane is often a plano-convex lens which can be designed, for example, according to the rules laid out above for the last optical elements LOE in each of the first to fifth embodiment. Examples are given e.g. in applicants US applications having serial numbers 10/931,051 (see also WO 03/075049 A), 10/931,062 (see also US 2004/0004757 A1), 10/379,809 (see US 2003/01744408) or in WO 03/077036 A. The disclosure of these documents is incorporated herein by reference.

Likewise, the invention can be implemented into catadioptric projection objectives having only one concave mirror, or catadioptric projection objectives having two concave mirrors in a arrangement different from that shown in the figures, or in embodiments having more than two concave mirrors. Also, use of the invention can be made independent of whether or not folding mirrors are present in the optical design. Examples of catadioptric systems are given e.g. in applicants US applications having serial numbers 60/511,673, 10/743,623, 60/530,622, 60/560,267 or in US 2002/0012100 A1. The disclosure of these documents is incorporated herein by reference. Other examples are shown in US 2003/0011755 A1 and related applications.

Likewise, the invention can be implemented into projection objectives without intermediate image, or with any suitable number of intermediate images depending on demand.

Table 1

Embodiment 1: NA = 1.45, β = -0.25, λ = 193.4 nm

SURF	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM.
0	0.000000	37.647680			62.000
1	200.438805	20.912608	SIO2HL	1.56018811	83.110
2	747.538013	7.881173			83.845
3	317.250503	20.945704	SIO2HL	1.56018811	86.831
4	22587.222465	11.951766			86.988
5	-354.957551	49.505975	SIO2HL	1.56018811	87.016
6	-278.404969	31.885410			92.050
7	133.981210	32.856595	SIO2HL	1.56018811	92.150
8	186.155059	11.833855			85.480
9	260.034334	38.111988	SIO2HL	1.56018811	85.440
10	-248.127931	0.945803			84.087
11	97.319012	29.863172	SIO2HL	1.56018811	63.308
12	247.011352	15.182258			54.518
13	0.000000	13.667911			46.858
14	-118.535589	9.039902	SIO2HL	1.56018811	47.472
15	-136.528381	10.289540			49.929
16	-117.640924	9.240335	SIO2HL	1.56018811	50.901
17	-267.170322	7.604882			57.478
18	-147.424814	27.656175	SIO2HL	1.56018811	58.338
19	-83.904407	29.670597			63.295
20	-79.022234	16.329258	SIO2HL	1.56018811	66.670
21	-99.429984	38.001255			76.192
22	-111.093244	49.234984	SIO2HL	1.56018811	86.007
23	-144.921986	0.952550			106.817
24	-6366.151454	44.409555	SIO2HL	1.56018811	119.243
25	-217.880653	270.750636			120.802
26	-219.739583	-239.183412		REFL	145.235
27	184.636114	269.507816		REFL	128.436
28	197.874974	37.626342	SIO2HL	1.56018811	86.078
29	524.125561	15.614096			81.640
30	-406.239674	8.985971	SIO2HL	1.56018811	81.383
31	106.800601	32.709694			77.510
32	-1162.346319	30.365146	SIO2HL	1.56018811	78.287
33	-161.881438	8.348534			81.054
34	-166.445156	11.418724	SIO2HL	1.56018811	81.127
35	-1076.211334	42.927908			95.134
36	-546.503260	41.443273	SIO2HL	1.56018811	113.022
37	-173.835591	0.952741			119.110
38	-372.875307	32.537548	SIO2HL	1.56018811	128.490
39	-210.380863	1.042699			131.802
40	303.213120	50.564746	SIO2HL	1.56018811	145.286
41	5346.623071	0.921057			144.413
42	262.055999	33.924688	SIO2HL	1.56018811	133.743
43	733.813747	0.928913			130.461
44	163.353186	39.409378	SIO2HL	1.56018811	116.482
45	349.938998	0.920003			111.971
46	279.917107	28.062402	SIO2HL	1.56018811	109.138
47	11299.235097	0.896338			104.077
48	88.608734	39.730068	SIO2HL	1.56018811	73.896
49	114.264419	0.751321			56.000
50	65.720894	25.021454	SAPHIR	1.92674849	49.523
51	131.441788	25.021469	SAPHIR	1.92674849	39.659
52	0.000000	1.000000	HIINDEX	1.55600000	18.066
53	0.000000	0.000000	AIR	0.00000000	15.503

Table 1A

ASPHERIC CONSTANTS

SRF	1	6	8	12	16
K	0	0	0	0	0
C1	-2.263569e-08	5.432610e-08	-7.143508e-09	2.619298e-07	-3.184960e-07
C2	-9.879901e-13	-7.797101e-12	1.564097e-11	-3.814641e-11	-3.142211e-11
C3	3.070713e-17	8.455873e-16	-1.599946e-15	1.148617e-14	-1.728296e-15
C4	-6.018627e-21	-6.875038e-20	3.060476e-19	-4.506119e-18	-1.249207e-18
C5	4.073174e-26	3.863486e-24	-2.788321e-23	-5.794434e-23	-9.678014e-24
C6	1.391778e-29	-1.112310e-28	1.126553e-27	4.244063e-26	-4.921692e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	22	26	27	28	31
K	0	0	0	0	0
C1	2.863527e-08	8.694636e-09	-6.654566e-09	5.614883e-08	-1.288689e-07
C2	1.884154e-12	1.385871e-13	-1.686449e-13	1.450774e-12	-4.820574e-12
C3	1.636375e-17	1.727286e-18	-2.470942e-18	1.892047e-16	5.082977e-16
C4	1.888300e-20	4.461465e-23	-2.362157e-22	6.954696e-21	-1.375138e-19
C5	-2.021635e-24	-7.172318e-28	7.757389e-27	-1.108417e-24	1.555422e-23
C6	1.591959e-28	3.081240e-32	-3.330142e-31	2.459404e-28	-2.481857e-28
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	34	36	41	47	49
K	0	0	0	0	0
C1	-1.177998e-07	-2.187776e-08	-1.577571e-08	-8.244653e-09	2.024084e-07
C2	-5.683441e-12	-8.068584e-14	3.706857e-13	4.957466e-12	1.422789e-11
C3	-5.647064e-16	8.600815e-17	-1.492063e-17	-2.442972e-16	3.923209e-15
C4	-7.031797e-21	-2.071494e-20	-9.742126e-22	6.741381e-21	4.845684e-19
C5	-1.902336e-24	1.290940e-24	6.498365e-26	2.034640e-25	-2.134986e-22
C6	2.891112e-29	-3.884318e-29	-9.630077e-31	-2.570056e-29	5.591977e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	9.579172e-34	0.000000e+00

Table 2

Embodiment 2 (b037b): NA = 1.35, β = -0.25, λ = 193.4 nm

SURF	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM.
0	0.000000	37.647680			62.000
1	526.196808	49.977602	SIO2HL	1.56018811	75.944
2	-256.668548	1.120100			85.473
3	696.160336	28.649736	SIO2HL	1.56018811	90.668
4	-2056.955285	22.244610			92.750
5	-195.811665	49.974335	SIO2HL	1.56018811	92.870
6	-158.185918	9.821764			101.539
7	138.796255	49.218181	SIO2HL	1.56018811	90.394
8	301.060143	1.660319			80.597
9	161.646552	42.095627	SIO2HL	1.56018811	78.153
10	-406.812049	0.979493			70.852
11	100.020556	24.469422	SIO2HL	1.56018811	52.354
12	102.330592	10.088496			38.573
13	0.000000	10.406389			37.226
14	-157.109979	8.950512	SIO2HL	1.56018811	38.841
15	618.822068	8.847956			46.776
16	-561.300665	33.147649	SIO2HL	1.56018811	51.388
17	-73.150544	9.448760			56.377
18	-69.300574	8.926672	SIO2HL	1.56018811	57.781
19	-86.551998	8.003693			64.608
20	-78.306541	10.360105	SIO2HL	1.56018811	66.592
21	-117.142798	2.915635			75.827
22	-356.673528	46.693825	SIO2HL	1.56018811	86.465
23	-108.386760	266.538313			90.245
24	-177.092218	-236.552196		REFL	129.567
25	200.462621	288.213928		REFL	136.687
26	604.677438	50.022575	SIO2HL	1.56018811	82.440
27	125.234518	13.901039			73.274
28	257.421526	34.367199	SIO2HL	1.56018811	73.449
29	111.034905	29.307766			73.890
30	-848.480773	29.119950	SIO2HL	1.56018811	74.404
31	-194.073508	7.840952			80.032
32	-225.307336	46.053997	SIO2HL	1.56018811	81.668
33	-535.709449	0.941640			105.651
34	-1622.810467	46.410355	SIO2HL	1.56018811	108.373
35	-173.207717	0.932943			113.398
36	-236.921577	22.327373	SIO2HL	1.56018811	116.764
37	-261.220038	0.938270			124.709
38	364.988031	40.936258	SIO2HL	1.56018811	142.520
39	11406.698081	0.943482			142.679
40	379.203162	36.840265	SIO2HL	1.56018811	142.867
41	-33782.420006	0.921857			141.929
42	245.879991	49.886843	SIO2HL	1.56018811	134.831
43	-10061.581161	0.883850			132.020
44	145.995266	39.892414	SIO2HL	1.56018811	105.854
45	375.256079	0.817132			99.565
46	86.107554	37.429431	SIO2HL	1.56018811	73.276
47	215.234027	0.667291			63.094
48	52.718236	26.546970	SIO2HL	1.56018811	42.800
49	0.000000	16.594510	SAPHIR	1.92674849	42.800
50	0.000000	0.999826	H2O	1.43612686	42.800
51	0.000000	0.000000	AIR	0.00000000	15.501

Table 2A

ASPHERIC CONSTANTS

SRF	1	6	9	12	14
K	0	0	0	0	0
C1	-8.448852e-08	-4.108258e-09	-6.153759e-08	4.456016e-07	-6.305745e-07
C2	-4.761055e-12	-9.598657e-12	-1.480269e-11	1.857407e-11	-7.903687e-11
C3	-1.420861e-16	1.072661e-15	1.473191e-15	1.064538e-14	-2.534563e-14
C4	-8.023974e-20	-6.889975e-20	-3.255374e-19	-5.079476e-18	-3.735078e-18
C5	1.173437e-23	2.314066e-24	3.131675e-23	1.056992e-22	1.905659e-22
C6	-1.454073e-27	-3.793935e-29	-6.955428e-28	7.981996e-26	-3.500146e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	20	24	25	26	29
K	0	0	0	0	0
C1	1.209336e-07	1.259532e-08	-4.077497e-09	1.111414e-07	-8.942189e-08
C2	1.869926e-11	3.424345e-13	-8.690596e-14	3.172584e-13	-1.116520e-13
C3	1.314270e-15	6.952906e-18	-1.505812e-18	3.429058e-19	4.168290e-16
C4	3.650689e-19	3.744203e-22	-8.583957e-23	-1.068048e-20	-2.231424e-19
C5	-5.603440e-23	-1.203108e-26	2.784182e-27	1.935865e-24	2.267328e-23
C6	9.844086e-27	6.714766e-31	-1.066606e-31	-5.318242e-29	-1.588914e-27
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	32	34	39	45	47
K	0	0	0	0	0
C1	-9.549663e-08	-5.673614e-09	-1.220571e-08	-2.613273e-08	1.649072e-07
C2	-3.034519e-12	-5.774683e-14	4.574492e-13	4.882999e-12	-4.982295e-13
C3	1.985443e-16	-1.715933e-16	-3.026161e-17	-2.171852e-16	-2.462341e-16
C4	-1.403621e-20	5.949307e-21	8.480395e-22	8.220913e-21	6.329880e-19
C5	2.496197e-24	1.220843e-25	-5.629908e-27	2.183741e-25	-1.498580e-22
C6	-1.598958e-28	-2.178077e-29	-3.377722e-32	-2.816869e-29	1.552461e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	1.520501e-33	0.000000e+00

Table 3

Embodiment 3 (b037a): NA = 1.45, β = -0.25, λ = 193.4 nm

SURF	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM.
0	0.000000	37.647680			62.000
1	178.098560	47.089109	SIO2HL	1.56018811	83.684
2	508.791874	0.982161			86.920
3	260.152118	29.610169	SIO2HL	1.56018811	89.203
4	-897.680969	14.988854			89.348
5	-224.555868	50.010854	SIO2HL	1.56018811	89.318
6	-167.290149	6.943751			94.603
7	185.350898	29.083481	SIO2HL	1.56018811	84.200
8	161.696842	4.567325			74.817
9	156.295097	29.687097	SIO2HL	1.56018811	74.801
10	-1628.579737	27.610587			72.999
11	116.709207	25.652869	SIO2HL	1.56018811	57.349
12	3359.816893	2.336800			52.702
13	0.000000	42.058143			50.890
14	-114.711496	34.899486	SIO2HL	1.56018811	53.065
15	-73.282662	4.817213			60.856
16	-72.166685	17.818288	SIO2HL	1.56018811	60.190
17	-80.823907	4.905081			66.269
18	-78.170209	34.642475	SIO2HL	1.56018811	65.802
19	-161.353349	3.907912			83.613
20	-250.115507	50.004289	SIO2HL	1.56018811	87.033
21	-130.504962	244.427626			94.956
22	-180.721067	-214.432541		REFL	135.011
23	179.125663	274.568868		REFL	126.490
24	337.886373	47.239794	SIO2HL	1.56018811	107.066
25	-899.516467	5.847365			104.221
26	-2346.009271	43.828445	SIO2HL	1.56018811	101.016
27	101.771490	35.484160			86.055
28	-4439.596410	23.703533	SIO2HL	1.56018811	86.263
29	-254.324560	5.801976			87.609
30	-445.540133	48.164461	SIO2HL	1.56018811	87.772
31	-735.213902	16.951226			100.097
32	-650.817086	49.961292	SIO2HL	1.56018811	102.416
33	-281.005458	31.479288			116.698
34	-649.019441	49.768062	SIO2HL	1.56018811	130.316
35	-215.856617	0.928162			134.641
36	312.849138	39.828764	SIO2HL	1.56018811	135.256
37	-1022.199791	0.857904			133.831
38	278.748013	42.635737	SIO2HL	1.56018811	128.369
39	-3295.326556	0.914469			126.650
40	128.656616	61.387113	SIO2HL	1.56018811	106.520
41	-2188.188515	0.730038			100.722
42	90.065507	18.596750	SIO2HL	1.56018811	69.706
43	93.775489	1.000000			60.097
44	73.203900	33.227474	SAPHIR	1.92674849	55.900
45	0.000000	11.657723	SIO2HL	1.56018811	55.900
46	0.000000	0.999913	HIINDEX	1.55600000	55.900
47	0.000000	0.000000	AIR	0.00000000	15.520

Table 3A

ASPHERIC CONSTANTS

SRF	1	6	8	12	14
K	0	0	0	0	0
C1	-3.797021e-08	4.091151e-08	9.284044e-09	1.793476e-07	-3.526789e-07
C2	-1.858357e-12	-7.880362e-12	2.927990e-11	-4.710051e-11	-5.029864e-11
C3	6.026920e-17	9.074630e-16	-2.187906e-15	2.197728e-15	-6.353989e-15
C4	-3.792813e-20	-7.153651e-20	3.131133e-19	-3.553387e-18	-2.243484e-18
C5	3.121506e-24	2.884237e-24	-3.422295e-23	-7.638265e-23	1.422334e-23
C6	-1.940311e-28	-4.358943e-29	2.472280e-27	2.576563e-26	-7.652798e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	18	22	23	24	27
K	0	0	0	0	0
C1	4.805447e-08	1.366493e-08	-7.247654e-09	2.039086e-09	-2.335210e-07
C2	6.053101e-12	3.157722e-13	-1.844324e-13	4.079171e-12	-3.581428e-12
C3	1.864225e-16	4.418704e-18	-3.130608e-18	3.415807e-19	8.204976e-16
C4	1.774391e-19	3.842541e-22	-2.876782e-22	-3.143532e-21	-1.472132e-19
C5	-1.538124e-23	-1.422352e-26	1.047999e-26	-6.009771e-26	1.193755e-23
C6	1.486597e-27	5.625242e-31	-4.798652e-31	5.373759e-30	-5.012293e-28
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	30	32	37	41	43
K	0	0	0	0	0
C1	-9.015949e-08	-4.710517e-08	2.981775e-08	7.825942e-08	-1.254855e-07
C2	-5.963683e-12	1.502154e-12	-1.562632e-15	-5.678508e-12	4.044789e-11
C3	-2.709599e-17	-1.008729e-16	-1.924785e-17	9.897699e-16	5.935178e-15
C4	1.782520e-20	-2.037099e-20	1.470777e-21	-1.257950e-19	-7.518165e-19
C5	-1.313151e-25	1.244695e-24	-9.287054e-26	1.131690e-23	5.626054e-23
C6	1.114296e-28	-7.926554e-29	2.454712e-30	-6.106697e-28	5.101190e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	1.494562e-32	0.000000e+00

Table 4

Embodiment 4: NA = 1.35, β = -0.25, λ = 193.4 nm

SURF	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM.
0	0.000000	37.647680			62.000
1	213.097095	21.139875	SIO2HL	1.56018811	81.073
2	980.962863	0.933467			81.638
3	312.309311	19.869666	SIO2HL	1.56018811	82.923
4	7050.227976	14.977212			82.853
5	-284.845054	46.899913	SIO2HL	1.56018811	82.842
6	-316.674517	31.820687			87.867
7	127.504953	32.199127	SIO2HL	1.56018811	90.842
8	177.687028	14.069304			84.748
9	233.816949	49.949045	SIO2HL	1.56018811	84.566
10	-272.601570	1.802731			81.010
11	92.974202	24.948435	SIO2HL	1.56018811	61.866
12	228.036841	31.795297			55.983
13	-128.436888	15.028089	SIO2HL	1.56018811	45.986
14	-208.039449	19.686225			50.292
15	-85.822730	9.039605	SIO2HL	1.56018811	51.590
16	-124.923386	5.248146			59.096
17	-134.255203	24.981296	SIO2HL	1.56018811	61.621
18	-86.028170	70.079618			66.114
19	-91.784845	49.926992	SIO2HL	1.56018811	78.125
20	-130.258172	3.354815			102.297
21	-819.889396	43.461173	SIO2HL	1.56018811	114.993
22	-193.549016	277.291798			117.690
23	-220.432400	-231.344649		REFL	147.536
24	175.171589	261.356424		REFL	120.087
25	222.618410	49.895981	SIO2HL	1.56018811	93.866
26	227.634130	10.722465			85.687
27	469.132386	43.799915	SIO2HL	1.56018811	85.491
28	112.693662	31.313114			76.622
29	12293.399547	31.702057	SIO2HL	1.56018811	77.313
30	-155.449641	4.962336			79.575
31	-219.506451	26.268152	SIO2HL	1.56018811	79.827
32	-1377.822971	32.354789			93.063
33	-519.892544	47.183977	SIO2HL	1.56018811	101.635
34	-163.140684	1.841108			110.786
35	-340.920966	26.977392	SIO2HL	1.56018811	116.967
36	-214.582539	2.006234			120.143
37	271.181444	53.143321	SIO2HL	1.56018811	127.047
38	-1118.441818	19.790952			125.887
39	0.000000	-14.609943			112.489
40	174.102740	52.205661	SIO2HL	1.56018811	107.954
41	-663.589997	3.836965			104.404
42	84.561977	46.625084	SIO2HL	1.56018811	71.481
43	95.046969	0.694913			51.033
44	64.492898	46.885676	SAPHIR	1.92674849	46.520
45	0.000000	1.000000	H2O	1.43612686	18.265
46	0.000000	0.000000	AIR	0.00000000	15.515

Table 4A

ASPHERIC CONSTANTS

SRF	1	6	8	12	15
K	0	0	0	0	0
C1	-7.766221e-09	3.921777e-08	-1.973978e-08	2.262385e-07	-2.849645e-07
C2	-1.414298e-12	-7.469962e-12	1.686856e-11	-3.111178e-11	-3.795087e-11
C3	2.026799e-16	9.877277e-16	-1.521195e-15	8.999889e-15	-4.195519e-15
C4	-9.311177e-21	-6.240165e-20	2.838141e-19	-4.631502e-18	-2.684695e-18
C5	8.983777e-26	3.683666e-24	-2.893390e-23	7.225241e-23	-2.249016e-23
C6	-5.139250e-30	-1.606542e-28	1.372152e-27	5.035383e-26	-5.606361e-26
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	19	23	24	25	28
K	0	0	0	0	0
C1	2.306275e-08	9.197905e-09	-7.280789e-09	8.044076e-08	-1.035389e-08
C2	1.672430e-12	1.297990e-13	-2.062090e-13	6.845761e-13	5.752946e-14
C3	-3.451288e-18	1.447412e-18	-3.885785e-18	8.440855e-17	3.412577e-16
C4	3.656429e-20	4.002605e-23	-3.101616e-22	-8.233892e-21	-1.247784e-19
C5	-5.091821e-24	-7.044663e-28	1.113163e-26	1.115110e-24	5.556509e-24
C6	5.148418e-28	3.011922e-32	-6.186058e-31	-3.079026e-29	1.295943e-27
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	31	33	38	41	44
K	0	0	0	0	0
C1	-1.291718e-07	-4.530057e-08	-1.801990e-08	-2.682021e-08	-1.900216e-07
C2	-4.385607e-12	-2.081953e-13	6.277450e-13	7.361672e-12	-4.832504e-11
C3	-2.255698e-16	1.680387e-16	-5.256278e-17	-3.951877e-16	-1.233010e-14
C4	-2.117620e-21	-4.155797e-20	-4.688822e-21	1.434967e-20	7.440284e-19
C5	-1.322919e-24	3.040355e-24	4.497908e-25	-3.980440e-26	1.430823e-22
C6	1.074049e-28	-1.238033e-28	-9.348185e-30	-2.642973e-29	-3.924075e-25
C7	0.000000e+00	0.000000e+00	0.000000e+00	1.163864e-33	0.0000

Table 5

Embodiment 5: NA = 1.6, β = -0.25, λ = 193.4 nm

SURF	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM.
0	0.000000	37.663108			62.000
1	192.084227	26.622297	SIO2V	1.56078570	87.833
2	1075.649716	0.946456			88.233
3	491.402040	19.101530	SIO2V	1.56078570	88.867
4	-934.209447	36.905290			88.935
5	125.340633	9.623977	SIO2V	1.56078570	90.013
6	122.019859	23.963817			87.312
7	252.185057	44.239148	SIO2V	1.56078570	87.669
8	-204.394078	0.923049			87.161
9	102.471834	52.852020	SIO2V	1.56078570	67.768
10	254.533994	9.305878			48.073
11	0.000000	52.418616			46.820
12	-75.641562	68.872834	SIO2V	1.56078570	58.068
13	-124.953275	39.621161			93.864
14	-835.558655	54.318921	SIO2V	1.56078570	126.993
15	-178.850083	0.948020			130.230
16	2111.392648	22.857019	SIO2V	1.56078570	132.098
17	-901.583067	358.679202			132.071
18	-225.015829	-231.613549		REFL	160.876
19	168.185189	261.594819		REFL	120.144
20	-736.571530	23.114077	SIO2V	1.56078570	81.485
21	132.965130	36.406211			86.933
22	-512.908458	28.535664	SIO2V	1.56078570	87.621
23	-185.099986	6.615931			92.898
24	-544.628556	33.807132	SIO2V	1.56078570	99.839
25	-547.431224	19.995820			114.885
26	-359.224408	99.479683	SIO2V	1.56078570	119.014
27	-168.873687	12.916761			143.505
28	313.449462	92.758623	SIO2V	1.56078570	165.026
29	983.057723	1.167054			158.153
30	227.152511	48.817493	SIO2V	1.56078570	148.584
31	684.382976	0.981700			144.866
32	144.775480	60.829967	SIO2V	1.56078570	121.541
33	1285.387522	0.899534			116.276
34	99.002284	39.642869	SIO2V	1.56078570	84.155
35	243.117451	0.805490			74.674
36	65.952055	54.681070	SAPHIR	1.92674849	54.379
37	0.000000	0.000000	AIR	0.00000000	15.530

Table 5A

ASPHERIC CONSTANTS

SRF	4	5	10	14	18
K	0	0	0	0	0
C1	4.332466e-08	5.983847e-08	4.678448e-07	-5.502311e-09	9.581997e-09
C2	-4.251613e-12	-1.394334e-11	1.214772e-11	6.759433e-14	1.191548e-13
C3	8.548420e-16	1.246293e-15	1.462858e-14	-2.777895e-18	5.628084e-19
C4	-7.822847e-20	-2.065935e-19	-5.084805e-18	1.850960e-22	7.255139e-23
C5	3.463295e-24	1.861321e-23	4.192361e-22	-7.883399e-27	-1.691943e-27
C6	-7.495559e-29	-7.372680e-28	1.456331e-26	1.533878e-31	3.619858e-32
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	19	20	21	24	26
K	0	0	0	0	0
C1	-5.661490e-09	8.762490e-08	-3.207763e-08	-6.520443e-08	4.364974e-09
C2	-1.921628e-13	-1.093121e-11	-5.311243e-12	4.777722e-13	-1.522836e-12
C3	-7.055884e-19	1.359734e-15	6.816058e-16	-7.895875e-17	-6.656442e-18
C4	-6.935220e-22	-2.479964e-19	-2.253013e-19	1.733738e-20	-2.640069e-21
C5	3.152816e-26	2.421781e-23	2.354847e-23	-2.097861e-24	2.889539e-25
C6	-1.191863e-30	-1.346005e-27	-1.003551e-27	1.235456e-28	-1.101803e-29
C7	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

SRF	29	33	35
K	0	0	0
C1	8.788855e-09	3.258556e-08	1.084860e-07
C2	-6.462954e-13	1.588293e-12	6.094001e-12
C3	-1.551858e-17	-1.752790e-16	1.646644e-16
C4	1.099566e-21	1.227022e-20	-9.287322e-20
C5	-1.930245e-26	-5.173475e-25	1.657126e-23
C6	1.160550e-31	1.295964e-29	-1.278529e-27
C7	0.000000e+00	-1.104258e-34	0.000000e+00

Claims

1. Projection objective for imaging a pattern provided in an object plane of the projection objective onto an image plane of the projection objective suitable for microlithography projection exposure machines comprising:
   a plurality of optical elements transparent for radiation at an operating wavelength of the projection objective;
   wherein at least one optical element is a high-index optical element made from a high-index material with a refractive index $n \geq 1.6$ at the operating wavelength.

2. Projection objective according to Claim 1, wherein the high-index material has a refractive index $n \geq 1.8$ at the operating wavelength.

3. Projection objective according to Claim 1 or 2, wherein the high-index material is sapphire.

4. Projection objective according to Claim 1 or 2, wherein the high-index material is germanium dioxide.

5. Projection objective according to one of the preceding Claims, wherein an object-side numerical aperture NA_{Obj} is greater than 0.3.

6. Projection objective according to Claim 5, wherein the object-side numerical aperture NA_{Obj} >0.36 in conjunction with an absolute reduction ratio of $|\beta| \leq 0.25$.

7. Projection objective according to one of the proceeding Claims, having a first high-index optical element and at least one second high-index optical element.

8. Projection objective according to Claim 7, wherein the first high-index optical element and the second high-index optical element are each made from a high-index material exhibiting birefringence defining an orientation of birefringence of each optical element, where the first and second high-index optical elements are installed differently with regard to the orientation of the birefringence such that effects of birefringence caused by the high-index optical elements are at least partly compensated.

9. Projection objective according to one of the preceding Claims, wherein the projection objective has a last optical element closest to the image plane and wherein the last optical element is at least partly made of a high-index material with refractive index $n > 1.6$.

10. Projection objective according to Claim 9, wherein the last optical element is a monolithic plano-convex lens made of a high-index material with refractive index $n > 1.6$.

11. Projection objective according to Claim 9, wherein the last optical element consists of at least two optical elements in optical contact with each other along a splitting interface, where at least one of the optical elements forming the last optical element consists of a high-index material with refractive index $n > 1.6$.

12. Projection objective according to Claim 9, wherein the last optical element consists of an entry side plano-convex lens element having a curved entry side and a planar exit side and an exit side plane parallel plate in optical contact with the plano-convex lens element along a planar splitting surface.

13. Projection objective according to Claim 12, wherein the plano-convex lens element consists of a high-index material with a refractive

index n > 1.6 and wherein the exit side plane parallel plate consists of fused silica.

14. Projection objective according to Claim 12, wherein the plano-convex lens element consists of fused silica and wherein the exit side plane parallel plate consists of a high-index material with a refractive index n > 1.6.

15. Projection objective according to Claim 11, wherein the last optical element is shaped as a plano-convex lens and a splitting surface is curved such that both optical elements contacted at the splitting surface are lens parts with similar refractive power.

16. Projection objective according to one of the preceding Claims, wherein the projection objective is designed as an immersion objective adapted with reference to aberrations such that an image side working distance between a last optical element and the image plane is filled up with an immersion medium with a refractive index substantially greater than 1.

17. Projection objective according to Claim 16, wherein the projection objective is adapted to an immersion fluid which has a refractive index greater than 1.4 at the operating wave length.

18. Projection objective according to Claim 17, wherein the projection objective is designed for 193 nm operating wavelength and wherein the immersion fluid is cyclohexane.

19. Projection objective according to one of the preceeding Claims 1 to 15, wherein the projection objective is designed as a solid immersion objective having a finite image side working distance in the order of the operating wavelength or below such that evanescent

fields exiting from an image side exit surface of the projection objective can be used for imaging.

20. Projection objective according to one of the proceeding Claims 1 to 15, wherein the projection objective is designed for solid immersion lithography where an image side exit surface of the projection objective is in mechanical contact with an incoupling surface associated with a substrate to be exposed.

21. Projection objective according to one of the preceding Claims, wherein an image side numerical aperture NA is greater than 1.3.

22. Projection objective according to one of the preceding Claims, wherein a pupil surface positioned closest to the image plane is positioned in a region of convergent beam between a region of a local maximum of beam diameter closest to the image plane and the image plane.

23. Projection objective having an image plane and a lens furthest therefrom and starting from which there is a convergent beam path up to the image plane, in which a pupil plane or system aperture is arranged at a distance of at least 10 mm on the image side of said lens.

24. Microlithography projection exposure method for imaging a pattern provided on a mask positioned in an object plane of a projection objective onto a substrate provided in an image plane of the projection objective, in which a microlithography projection objective according to at least one of the preceding claims is used and an immersion fluid is introduced between a last lens of the microlithography projection objective and the substrate to be exposed.

25. Method according to Claim 24, in which an immersion fluid is used which has a refractive index greater than 1.4 at an operating wavelength of the projection objective.

26. Method according to Claim 25, in which the immersion fluid has a refractive index greater than 1.5 at the operating wavelength.

27. Microlithography projection exposure method for imaging a pattern provided on a mask positioned in an object plane of a projection objective onto a substrate provided in an image plane of the projection objective, in which an image-side last optical element of a projection objective being used is wrung or pressed onto the object to be exposed comprising the following steps in the given sequence:
positioning the projection objective and the substrate to be exposed relative to one another;
contacting the exit surface of the projection objective and an incoupling surface of the substrate;
aligning the mask relative to the projection objective such that a desired pattern region of the mask is imaged onto a target area of the substrate in contact with the exit surface of the projection objective.

28. Method according to Claims 27, wherein the steps are repeated for a number of juxtaposed target areas on the substrate.

29. Method according to Claims 27 or 28, wherein a thin transparent membrane is placed between the substrate to be exposed and the exit surface of the projection objective.

30. Method according to one of Claims 24 to 29, in which a microlithography projection objective according to one of Claims 1 to 23 is used.

31. Microlithography projection exposure method for imaging a pattern provided on a mask positioned in an object plane of a projection objective onto a substrate provided in an image plane of the projection objective, in which a microlithography projection objective is used and an immersion fluid is introduced between a last lens of the microlithography projection objective and the substrate to be exposed, wherein Cyclohexane is used as immersion fluid.

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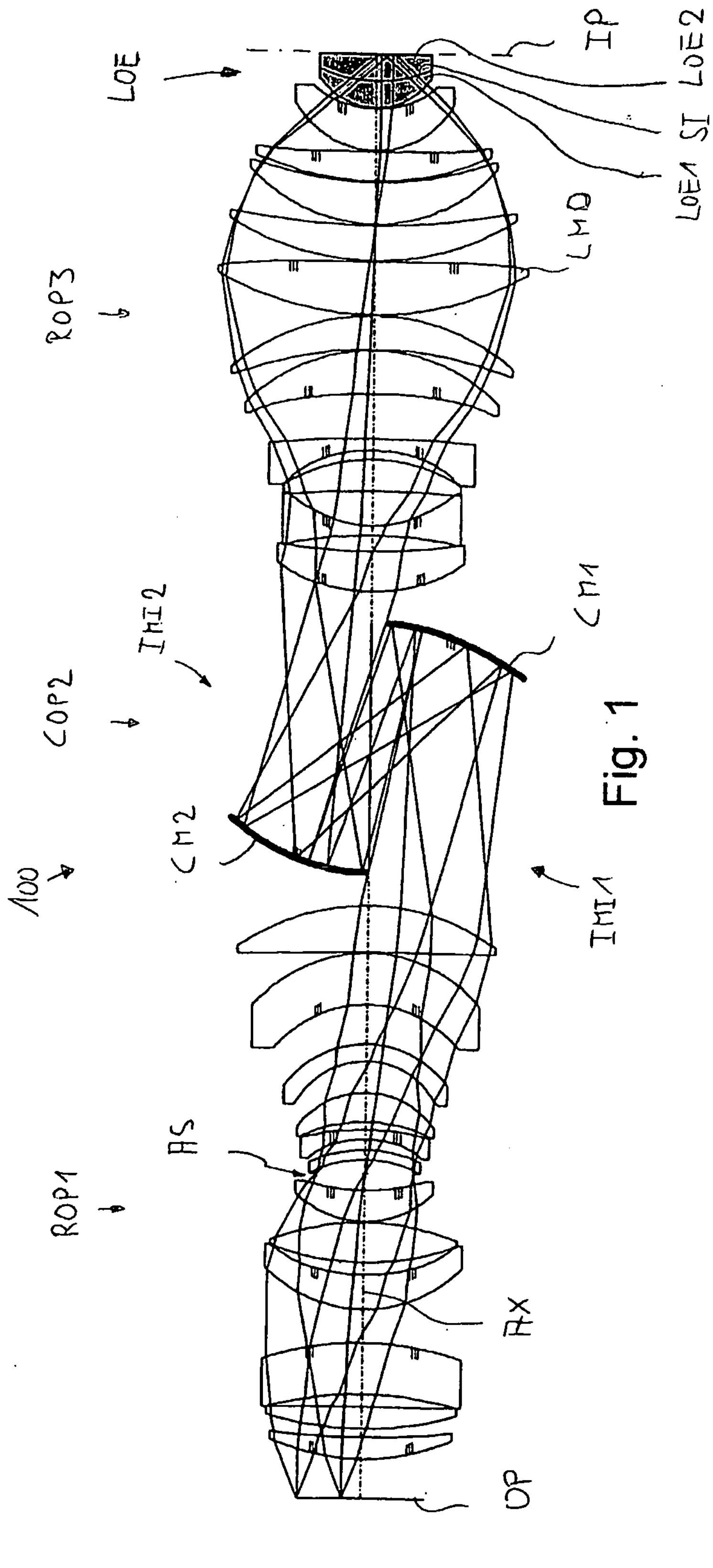
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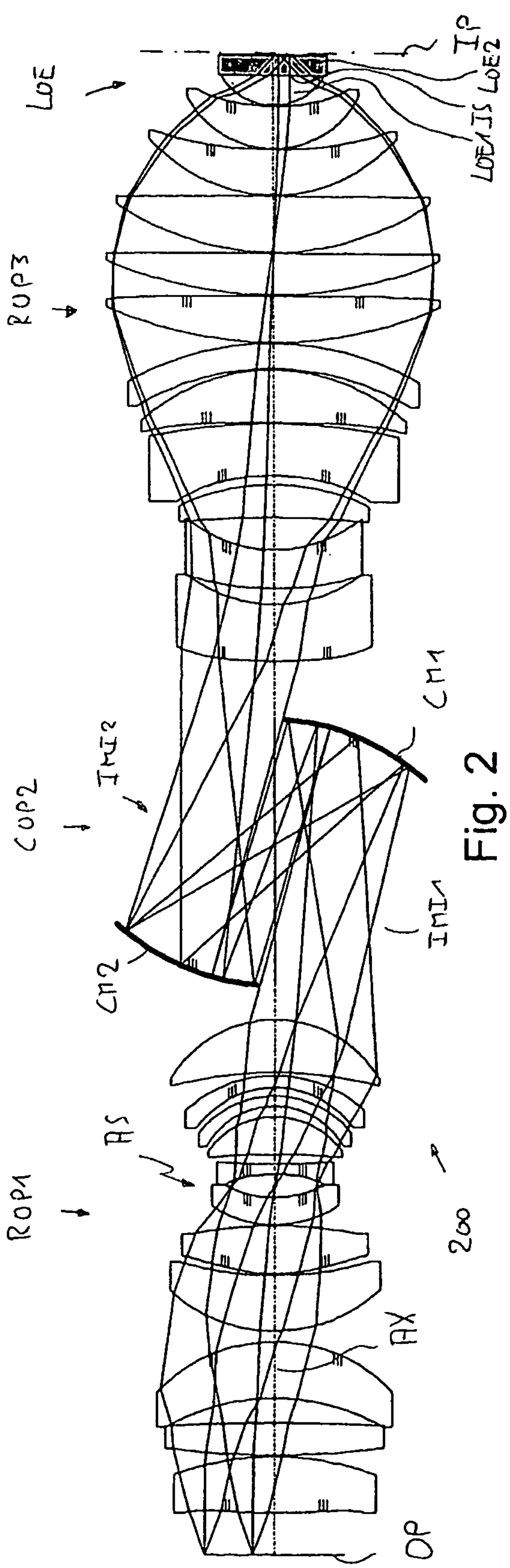
IP
LOE2
SI
LOE1
LMD
ROP3
IMI2
CM1
COP2
CM2
100
IMI1
AS
ROP1
AX
OP

Fig. 1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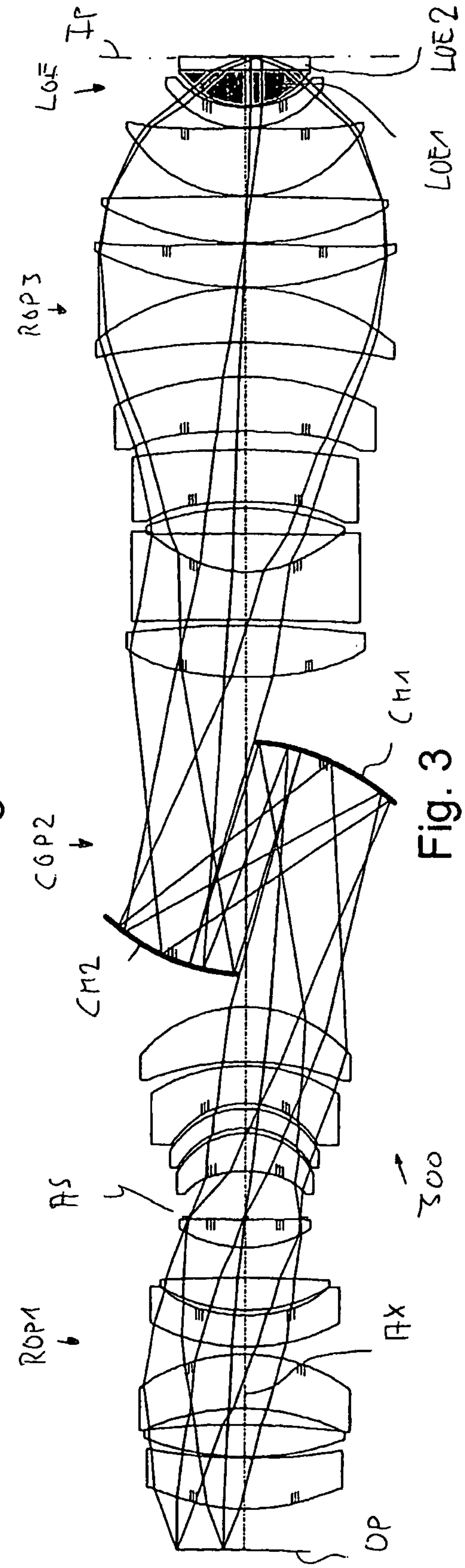
IP
LOE2
LOE1
IS
ROP3
COP2
IMI2
CM1
CM2
IMI1
AS
ROP1
200
AX
OP

Fig. 2


LOE
IP
LOE2
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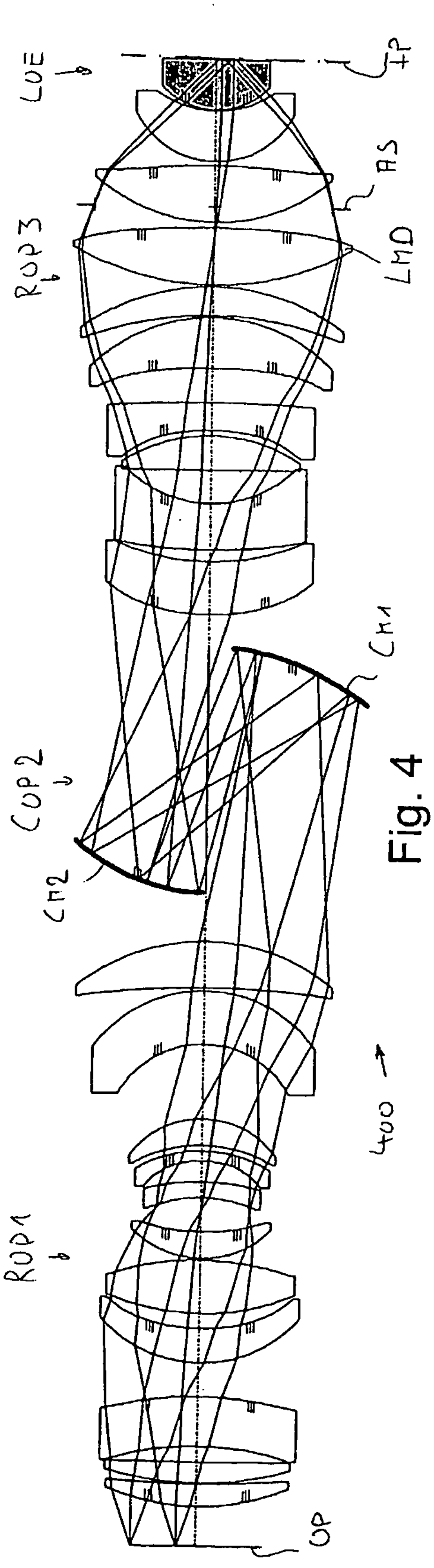
AX
OP

Fig. 3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LMD
ROP3
CM1
COP2
CM2
400
ROP1
OP

Fig. 4

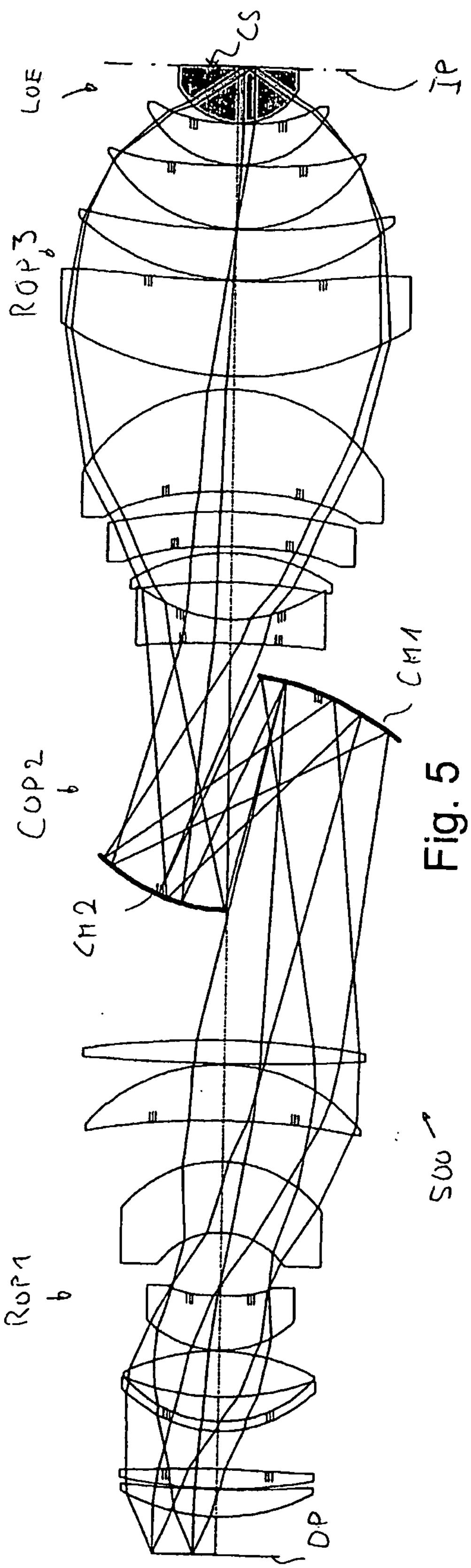
CS
LOE
IP
ROP3
CM1
COP2
CM2
500
ROP1
OP

Fig. 5